A comparison of visual hallucinations across disorders

R. Dudley , C. Aynsworth , U. Mosimann , J-P. Taylor ,
D. Smailes , D. Collerton , S. McCarthy-Jones , P. Urwyler

PII: S0165-1781(18)31877-8
DOI: https://doi.org/10.1016/j.psychres.2018.12.052
Reference: PSY 11983

To appear in: *Psychiatry Research*

Received date: 9 October 2018
Revised date: 6 December 2018
Accepted date: 7 December 2018

Please cite this article as: R. Dudley , C. Aynsworth , U. Mosimann , J-P. Taylor , D. Smailes , D. Collerton , S. McCarthy-Jones , P. Urwyler , A comparison of visual hallucinations across disorders, *Psychiatry Research* (2018), doi: https://doi.org/10.1016/j.psychres.2018.12.052

Highlights

- Visual hallucinations occur to differing degrees across disorders
- Hallucinations are usually considered as occurring in a single modality
- We examined hallucinations in people with eye disease, psychosis, and dementia.
- We found that single modality hallucinations varied in prevalence across disorders
- Multisensory experiences are more distressing and more likely to be considered real

A comparison of visual hallucinations across disorders

Running head: Multimodal visual hallucinations

R. Dudley*[,a,b], C. Aynsworth[b], U. Mosimann[c,d], J-P.Taylor[e], D. Smailes, D [f] Collerton[e,g], S. McCarthy-Jones [h] P. Urwyler[c,d,e]

[a] Gateshead Early Intervention in Psychosis Service, Northumberland, Tyne and Wear NHS, UK

[b] School of Psychology, Newcastle University, Newcastle upon Tyne, UK

[c] University Hospital of Old Age Psychiatry, University of Bern, Bern, Switzerland

[d] ARTORG Center for Biomedical engineering, University of Bern, Bern, Switzerland

[e] Institute of Neuroscience, Newcastle University, Campus for Ageing and Vitality, Newcastle upon Tyne, UK

[f] Department of Psychology, Northumbria University, Newcastle upon Tyne, UK, NE1 8ST

[g] Older People's Psychology Service, Northumberland, Tyne and Wear NHS Foundation Trust, Bensham Hospital Gateshead, UK

[h] Department of Psychiatry, Trinity College Dublin, Ireland

word count 4197

Correspondence to: Robert Dudley, Early Intervention in Psychosis service, Tranwell Unit, Queen Elizabeth Hospital, Gateshead, NE10 9RW Tel: +44(0) 191 441 6580 email: rob.dudley@ntw.nhs.uk

Abstract

Research into hallucinations typically regards them as single sensory or unimodal experiences leading to a comparative neglect of co-occurring multi-sensory hallucinations (MSH). People with psychosis who have visual hallucinations (VH) report high rates of hallucinations in other senses (auditory, olfactory, tactile). However, it is not known if this is similar to other groups who report VH. Consequently, this study explored MSH in four different patient groups who all had current VH. Archival data from standardised assessments of visual hallucinations in people with psychosis (n=22), eye disease (ED) (n=82), Lewy body Dementia (LBD) (n=41), and Parkinson's disease (PD) (n=41) determined the presence of MSH. People with psychosis and visual hallucinations reported significantly higher rates of MSH (auditory, 73%; tactile, 82%; olfactory/gustatory hallucinations, 27%) than the LBD group (auditory, 21%; tactile, 28%; olfactory/gustatory, 6%), ED (auditory, 1%; tactile, 11%; olfactory/gustatory, 0%) and PD patients (auditory, 3%; tactile, 8%; olfactory/gustatory, 3%). Regardless of diagnostic grouping, participants with MSH reported greater conviction that the VH were real, and reported greater distress. People with psychosis with VH report high rates of MSH unlike groups of older adults with VH. These between group differences in MSH prevalence have implications for clinical practice and theory.

Key words: Visual hallucination; Psychosis; Dementia; Eye disease;

1. Introduction

Visual hallucinations (VH), or visions, are defined as visual percepts that are experienced when fully conscious but in the absence of the corresponding external stimulus (Waters *et al.*, 2014). VH are common in a number of neurodegenerative disorders. Up to 93% of people with Lewy body dementia (LBD) report VH (Ballard *et al.*, 1997), as do up to 75% of people with Parkinson's disease (PD; Barnes & David, 2001; Williams, Warren & Lees, 2008). People with eye disease (ED) also often report VH (60%, (Graham *et al.*, 2011)). In comparison, VH are less common in psychosis (27%, (Waters *et al.*, 2014)). For people with psychosis, auditory hallucinations (AH) are much more common (Bracha *et al.*, 1989) than VH. For instance, McCarthy-Jones *et al*., (2017) reported liftetime prevalence of 64% and 80% for AH, in two large samples of people with psychosis, whereas prevalence of VH was 23% and 30% respectively. The opposite pattern is reported by people with neurodegenerative conditions where AH are less frequently reported than VH (Ballard *et al.*, 1997, Fenelon *et al.*, 2000). For instance, Inzelberg *et al*. (1998) reported prevalence of VH in people with PD as 22% to 38% whereas AH were less frequent (8%). The reason why both AH and VH are present in such disorders, and yet show opposite ratios of prevalence, remains unclear.

When considering this literature, hallucinations are typically treated as if they are separate, discrete sensory experiences occuring in only one distinct modality (i.e. unimodal hallucinations). However, hallucinations can occur in more than one sensory domain in which instance they are termed multi-sensorty hallucinations (MSH) or multimodal hallucinations (MMH). When people with psychosis are specifically asked if they experience a range of hallucinatory phenomena across

visual, auditory, tactile and olfactory domains then MMH are often reported. For example, Lim *et al*. (2016) found that lifetime reporting of MMH was twice (53%) that of uni-modal hallucinations (27%). Lim *et al.* (2016) conclude that MMHs are a characteristic feature of schizophrenia spectrum disorders. Llorca *et al*., (2016) explored MMH with people with PD (n=100) and people with schizophrenia (n=100). When asking about the past week they found a higher prevalence of VH than AH in the PD group (88% and 45% respectivley) which was broadly the opposite to the schizophrenia group (55% VH and 83% AH). However, the combination of auditory and visual hallucinations was the most frequent for both PD and schizophrenia groups. Other than in PD, where they were seemingly commonly reported (Llorca *et al.*, 2016), the prevalence of MMH is yet to be explored in other conditions. Therefore, this study extends the understanding of MMH across groups of people with psychosis, LBD, ED or PD.

The work reported to date typically considers MMH in terms of the number of sensory domains that people report the experiences within but not the nature and relationship of these multimodal experiences. At least two important dimensions of MMH have already been identified (Lim *et al.*, 2016). The first is a temporal dimension in that MMH may be serial or simulateneous. Serial MMH are hallucinations that occur in more than one sensory modality but occur at different times. For example, someone may report seeing a vision of a person, and at a later point report hearing a voice of someone speaking but importantly there is a temporal difference and the voice does not co-occur with the vision. Simultaneous MMH are defined as hallucinations that occur in more than one sensory modality at the same time e.g. someone sees a vision of a person whilst also hearing a voice of someone speaking.

A second potentially important dimension of MMH relates to the attribution of the agency or identity of the hallucination. The hallucinations in different modalities may be experienced as originating from the same agent/entity (related) or as coming from different agents/entities (unrelated). When combined with the temporal dimension, this gives four potential possibilities. The first is a simultaneous-related MMH. An example of this would be seeing an entity who also speaks. The second is a simultaneous-unrelated MMH, which could involve seeing one entity whilst hearing a voice recognised as belonging to another entity. Third, there may be serial-related MMH. An example of this would be seeing an entity at one time, and then at a later time feeling the touch of the (then unseen) entity. Finally, there is the possibility of serial-unrelated MMH, such as seeing an entity at one time and then feeling the touch of another entity at a later time (Lim *et al.*, 2016).

In an attempt to consider the multimodal nature of VH, Dudley *et al*., (2018) investigated MMH in people with psychosis using the North East Visual Hallucination Interview (NEVHI; (Mosimann *et al.*, 2008)) which allowed exploration of whether the experiences were related or not. Participants who reported having VH were asked whether they also had other hallucinations and whether these experiences were serial or simultaneous. Then the identity dimension was ascertained by asking if the VH ever spoke to, touched the person etc. Dudley *et al*., (2018) found that nearly all (95%, 21/22) the participants had serial unrelated hallucinations in that they all reported VH and also unrelated AH. Furthermore, they very often reported VH with related hallucinations in other sensory modalities (86%). The most frequent combination was of 3 senses; VH that talked to and touched the individuals. Hence, for people with VH in the context of psychosis, their VH were not silent, unimodal experiences but were better understood to be multisensory experiences that were

seen as related. Understanding the temporal and identity dimensions of multimodal hallucinations may have important theoretical and clinical implications.

In terms of clinical implications, for people with psychosis the presence of VH is associated with greater distress, and disability (Mueser *et al.*, 1990). If VH are actually better understood as related MMH then it may help explain this impact. If VH have an auditory and tactile component that are seen to be related it may mean that people are more convinced that the experience is real and this greater conviction may lead to greater distress (Collerton and Dudley, 2004).

Besides clinical utlilty, understanding the nature of mulitisensory experiences could have important theoretical implications. Having established the relatedness of MMH in people with psychosis the aim of the present study was to explore the prevalence of related MMH across groups of people with psychosis, LBD, ED and PD which are conditions defined by the high prevalence of VH. The work purposefully takes a transdiagnostic approach to understanding and describing VH. This is consistent with the NIMH Research Domain Criteria (RDoC; (Cuthbert and Insel, 2013)), which suggests that our understanding of hallucinations might be enriched by moving beyond the confines of categorical diagnoses and incorporating what is known about hallucinations across populations/diagnoses (Ford *et al.*, 2014). It could be that related MMH are the result of a general proneness to hallucinations (van der Gaag, 2006) whereas unimodal or unrelated MMH experiences may rely on domain specific processes (Collerton *et al.*, 2005).

Therefore, this study explored in more detail whether people with VH in the context of ED, PD, DLB, or psychosis report MMH. Specifically, the aim was determine the prevalence and impact of related multimodal hallucinations. The work was purposefully exploratory and largely descriptive and drew on existing, archival

data sets. The focus of the work was on the identity dimension and to what extent people with VH in these different conditions report related hallucinatory experiences which has not been previously considered across these disorders.

2. Method

2.1 Participants

Four groups of people who all reported VH participated, consisting of 82 people with Eye Disease (27M, 55F) aged between 57-99 (M=80.07, SD=8.13), 41 with Parkinson's disease (21M, 20F) aged between 52-89 (M=72.63, SD=9.48), 31 with Lewy Body Dementia (20M, 11F) aged between 61-89 (M=77.65, SD=7.58) and 22 people with psychosis (12M, 10F) aged between 19-34 (*M*=24.3, *SD*=4.03). Total sample size was 176.

Participants met inclusion and exclusion criteria for the original study that their data are derived from and are described in the original published articles (Dudley *et al.,* 2018, Makin *et al.*, 2013, Mosimann *et al.*, 2008, Taylor *et al.*, 2011, Urwyler *et al.*, 2014).

Participants were free from significant hearing impairment and provided informed consent. PD and LBD patients were only included if they had no visual field defects on neurological examination. Data was only included if people reported VH within the last month of data collection. This excluded a further 136 participants from original studies as they did not report current VH experiences.

2.2 Measures

The North East Visual Hallucination Interview (NEVHI; Mosiman et al., 2008) was completed by all the participants. This is a 20 item semi-structured interview that assesses the phenomenology of VH and its emotional, social and behavioural

impact. The NEVHI specifically explores related MMH by asking how people's visions interact with other sensory modalities, such as auditory experiences - "Do your hallucinations ever speak or make noises?", olfactory/taste experiences - "Are your hallucinations ever associated with an odd taste or smell?", and tactile experiences- "Does it ever feel like your hallucinations are touching you?". The NEVHI also addresses the emotional impact of VH asking whether VH are "distressing or frightening", and "frustrating and irritating" rated on a three point scale (0=never, 1=sometimes, 2=always). The interview also rates people's appraisals of the VH by asking "When you are having a hallucination do you ever believe that it is real?". For each study the NEVHI was administered by experienced clinicians/researchers. The measure has high internal consistency (α=.71) and good inter-rater reliability (κ=.83).

The following measures were used with the ED, PD and LBD groups but not with the people with psychosis. Binocular best visual acuity expressed in decimals (i.e. 1.0 vision=100% vision; equals to 6/6 vision), was examined at a test distance of 40 cm (Hohmann and Haase, 1982). The Mini Mental State Examination (MMSE) (Folstein *et al.*, 1975) was used to assess cognition. To assess executive and language skills the verbal fluency (FAS test) and category fluency test were administered (Lezak *et al.*, 2004). The severity of motor features and the impairment in functional activity were assessed using the Unified Parkinson's disease rating scale (UPDRS) part II and part III, respectively (Jenkinson *et al.*, 1997). The Epworth Sleepiness scale (ESS) was used to assess day- time sleepiness (Johns, 1991). The Mayo sleep questionnaire (Boeve *et al.*, 2002) was used to determine the presence of rapid eye movement (REM) sleep behaviour disorder (RBD) symptoms.

2.3 Data analysis

Group differences in the prevalence, emotional response to the VH, and the conviction that the VH was real were compared using appropriate categorical analyses (Chi square and Fisher exact tests). In addition to disorder group comparisons the data was clustered according to whether people reported unimodal or multimodal experiences based on whether participants endorsed the 3 questions asking about auditory, tactile or olfactory/gustatory experiences (that co-occur with their vision). Participants who scored either a “1=sometimes” or “2=always” on any of those questions where considered to have related MMH. This grouping variable was used to compare NEVHI responses for emotional responses and conviction. If people endorsed the questions as a 1 or above, it was rated at a “yes/present”, whereas those scored 0 were classified as a “no”.

2.4 Ethical considerations

The data from the NEVHI was collected as part of the primary research studies referenced above, all of which were approved by NHS Ethics committees and were registered with the local NHS trust research and development department. All participants gave informed consent to participate in the original research. As the data was subject to a secondary analysis not identified at the time consent was gained, permission to use this data was sought from an NHS ethics approval committee. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration.

3. Results

3.1 Missing data

Given the presenting difficulties in older adult populations, not all of the questions on the NEVHI were completed. For the psychosis group, all data was collected. Owing to the preliminary state of the research, participants with missing data were omitted which accounts for the variations in sample size for each question answered.

3.2 Demographics

Table 1 summarizes the demographics and clinical characteristics. As expected, the groups differed in age, in that the people with psychosis were younger than the other groups. The ED group differed from the PD group in age. Also, the ED group had the lowest visual acuity score. The LBD group had significantly lower scores in all cognitive measures (MMSE, verbal fluency, and categorical fluency) and significantly higher UPDRS and ESS scores compared with other groups.

Table 1 about here please

3.3 Prevalence of related MMH

Table 2 indicates how commonly people with VH also report related tactile, auditory or olfactory/gustatory experiences. As can be seen, related MMH were very common in people with psychosis who report VH (86.4%). In contrast, they were rare in people with VH in the context of ED (3.7%) and PD (10.3%). Those with LBD reported intermediate rates (32.1%) of related MMH.

Group comparisons using Fisher exact test indicated differences between the groups for all three sensory domains (as noted in Table 2). Further crosstab analysis demonstrated that differences in the prevalence of related tactile and visual MMH in those with ED and neurodegenerative conditions were not significant; whereas the PD group reported lower levels of related tactile and visual MMH than did the LBD group. People with psychosis reported significantly more tactile and visual MMH than the other three groups.

In terms of the prevalence of related auditory and visual MMH, the difference between the ED and PD groups was not significant. The LBD group reported significantly higher levels of related auditory and visual MMH than the ED group ($p<0.001$) and the PD group ($p=0.013$). People with psychosis reported significantly higher levels of related auditory and visual MMH than the other three groups.

Table 2 about here please

The prevalence of related olfactory/gustatory and visual MMH was higher in the psychosis group than in the than in the PD group ($p=0.004$). No other group differences were significant.

3.4 Emotional response to and Conviction in VH (MMH)

Table 3 reports participant's ratings of their emotional reactions to seeing their visions and their belief that their visions are real according to whether people reported unimodal or MMH. Participants with MMH were significantly more likely to rate their VH as irritating ($p=.000$), more distressing ($p=.000$), and more likely to report belief in their VH as being real ($p=.014$).

Table 3 about here please

4. Discussion

This study explored related multimodal hallucinations (MMH) across groups of people with psychosis, Lewy Body Dementia (LBD), eye disease, (ED) and Parkinson's disease (PD) all of whom reported visual hallucinations (VH). Related MMH were much more common in psychosis than in PD, ED, with DLB rates being intermediate. People who experienced related MMH were more distressed, frustrated and expressed stronger conviction that the VH was real than those experiencing unimodal hallucinations.

These findings, and those of previous research on MMH suggest a need for models that can account for both unimodal and multimodal hallucinations. Previous research has indicated that people with PD and DLB report much higher levels of VH than AH (Inzelberg *et al.*, 1998) which is the opposite pattern to people with psychosis who report higher rates of AH than VH (McCarthy-Jones *et al*., 2017). Such findings may suggest domain specific explanations for these unimodal experiences. However, MMH are more common than unimodal hallucinations in people with PD and people with psychosis (Llorca *et al.,* 2016) in that people report hallucinations in a number of sensory domains. Hence, models need to explain these multimodal experiences perhaps by proposing a common hallucinatory process that leads to hallucinations across a number of domains. However, given the differing prevalence rates of AH and VH, it may still be possible that there are modality specific processes and that people are affected separately in two or more of these sensory domains at least when accounting for serial unrelated hallucinations. However, the present research indicated that people with VH across a range of

disorders, differed in rates of simultaneous related MMH. In particular, when people with psychosis report VH it is very likely that they will be experienced as MMH with their visions also talking to and touching them. Whilst single sensory experiences like only having VH (as in ED) or only having AH (as in many people with psychosis) may be accounted for with domain specific unimodal explanations (Collerton, *et al*., 2005) where people report multimodal experiences these may need to be explained by different mechanisms.

Recently it has been proposed that hallucinations may be understood within a generative model of perception (Friston, 2010). In this account prior experiences are combined with observed sensory data within a hierarchical neural system to reduce perceptual errors (Sterzer *et al*., 2018). In effect the decision about whether an experience is real or imagined arises from a combination of: i) the quality of the sensory data that people are relying on which can be degraded owing to perceptual impairments as is obviously the case for people with eye disease; ii) a judgement about the source of the material which can be affected by a bias towards external sources as revealed in people with psychosis by their performance on reality monitoring (Aynsworth *et al.*, 2017) and reality discrimination tasks (Bristow *et al.*, 2014); iii) and the role of expectation or prior beliefs (Sterzer *et al., 2018)*. To some extent the groups investigated in this current study may differ in the degree to which the quality of the data, the judgement process, and expectation may play a role in the experience of VH.

Such predictive coding models seem well suited to explaining the co-occurrence of symptoms like hallucinations and delusions in people with psychosis, and may be valuable in understanding these related MMH. Our findings show that older people with visual perceptual impairments (ED) or those with intact cognitive

processes (PD), report very low rates of related hallucinations. With the older adult groups as cognitive impairment increases there is a greater likelihood of reporting related MMH (DLB). People with PD and those with DLB have been shown to tend to see faces in neutral objects (pareidolia) which implies greater reliance on top down processes (Mamiya *et al.*, 2016, Uchiyama *et al.*, 2012, Uchiyama *et al.*, 2015, Yokoi *et al.*, 2014). It may be that as people rely more on expectancy to help make sense of the ambiguous sensory data where there is greater cognitive impairment it may lead to difficulty distinguishing real from imagined.

However, related MMH are even more common in people with psychosis who owing to their much younger age typically have less perceptual impairment and are less likely to experience the cognitive problems with attention, concentration and memory seen in PD and DLB. Hence, it would seem unlikely that greater perceptual and cognitive impairment alone would explain greater related MMH. People with psychosis are reported to be less influenced by past expectancy and are more driven by the sensory data (Sterzer *et al*., 2018). To be consistent with a generative model of perception it may be that different processes or combinations of processes contribute to the increased rate of reporting of related MMH in people with psychosis with VH.

Clearly there are a number of limitations that need to be held in mind. The obvious limitation is our use of archival data. We have previously reported on the multisensory nature of VH for the 22 people with psychosis (Dudley et al., 2018) used in this present study. However, we also report entirely new data on 82 people with Eye Disease, 41 with Parkinson's disease and 31 with Lewy Body Dementia. Hence, the previously presented data represents 12.5% of the current sample and, of course, the comparison across group is novel. The source studies for

the Eye Disease, Parkinson's and Lewy Body dementia groups did not specifically investigate the coexistence of VH with other modalities or the relatedness of MMH. However, in the source studies the participants all completed the same assessment of VH allowing exploration of the relatedness of MMH. The judicious use of archival data is important as it maximises the use of existing data and avoids unnecessarily burdening participants with additional measures solely for examining exploratory questions. Of course, the groups differed in diagnosis, and to some extent age and gender. However, this is entirely in keeping with a transdiagnostic approach (Cuthbert and Insel, 2013) and was used to try and examine similarities and differences in VH across these disorders.

A key limitation though is that whilst we identified differences in the rates of related MMH we were not able to directly test the mechanisms that may potentially account for related MMH VH. Here, the first task was to explore, in detail, the relatedness and agency of the VH. If the groups did not differ in the relatedness of the MMH then there would be little to learn from the performance on secondary measures. However, having established some apparent differences in the phenomena reported, a future investigation of this area could a) systematically assess hallucinations across a range of modalities (Lim *et al*., 2016), b) explore the relatedness of these phenomena (Dudley *et al*., 2018), c) explore cognitive and perceptual abilities as well as testing reality discrimination, reality monitoring, and top down processing using pareidolia type tasks, as well asking about imagery (Aynsworth *et al.,* 2017) and trauma history (Solsevik *et al.,* 2016).

A further limitation is that owing to the amount of missing data we could have underestimated the prevalence of related MMH in the older adult groups. Whilst possible, it is important to note the high response rate on the AH question (130/137)

for the older adult's groups. This is likely to be a commonly experienced hallucination in addition to VH, but we still see very little reporting of AH. Therefore, it is possible that the participants were not experiencing other undetected related hallucinatory phenomena.

It is possible that people reported unrelated hallucinations, perhaps hearing a voice or a sound that was not related to the vision. These would be multimodal hallucinations as well, but would be considered unrelated hallucinations, and we would assume would be temporally unrelated as well. This information was collected for the psychosis group (and 21 of the 22 also reported other AH experiences, Dudley *et al*, 2018) but not for the other groups. Previous studies of people with VH in the context of ED, DLB and PD have asked systematically about the presence of AH or hallucinations in other modalities and reported that they are much less common than VH (Ballard *et al.*, 1997, Fenelon *et al.*, 2000), so whilst we may have missed these experiences they are not likely to have been as common as in people with psychosis.

It is striking that VH for most of the participants, with the exception of the psychosis sample, are not reported as MMH. Of course, reporting of VH is less frequent than AH in people with psychosis. AH are generally reported as unimodal experiences (McCarthy-Jones *et al.*, 2017), so we may be examining a somewhat different set of processes in people with psychosis and VH than those with Psychosis and AH.

We found that that there were higher levels of distress, and conviction in those people with MMH. However, this grouping was largely composed of people with psychosis, who may for other reasons besides the nature of their hallucinations report more distress and conviction. Whilst the questions were related to the

distress of seeing the vision, clearly, future research with larger groups of participants (including Alzheimer Dementia, non-clinical populations) could consider if multimodality rather than diagnosis is most indicative of distress and conviction. Of course, other factors such as the content, frequency, persistence and appraisals of what it means to see visions (Dudley *et al.*, 2012) may all also play a role in the distress and conviction reported (Thomson *et al.*, 2017).

Possible clinical implications of this work are that a brief normalising rationale that explains that visions are common, and are a result of impaired perceptual processes may be helpful and reduce distress in people with ED, or PD. Where there is cognitive impairment or particularly in people with psychosis, where multimodality is common and conviction and distress are high, it may be that normalisation alone may be insufficient and a number of reality testing approaches are needed to help the person learn that their vision cannot cause them harm, and that they are safe (Wilson *et al.*, 2016).

Acknowledgements

We would like to thank all the participants whose data was used in this study. We extend our thanks to the Low Vision Clinic at the Royal Victoria Infirmary, Newcastle upon Tyne; Newcastle Society for Blind People; Gateshead Visually Impaired Forum; Northumberland Blind Association; additional (and previous) members of the Newcastle Hallucination Group: Neil Archibald, Selina Makin, David Burn, Ian McKeith; Dr. David Beaumont, Daniel Bearn, Jenny Dean, Gemma Grewer, Allison Killen, and Jessica Redman for their help with recruitment.

References

Aynsworth, C., Nemat, N., Collerton, D., Smailes, D. & Dudley, R. (2017). Reality monitoring performance and the role of visual imagery in visual hallucinations. *Behav Res Ther* **97**, 115-122.

Ballard, C., McKeith, I., Harrison, R., O'Brien, J., Thompson, P., Lowery, K., Perry, R. & Ince, P. (1997). A detailed phenomenological comparison of complex visual hallucinations in dementia with Lewy bodies and Alzheimer's disease. *Int Psychogeriatr* **9**, 381-8.

Boeve, B. F., Silber, M. H., Ferman, T. J. & Smith, G. E. (2002). Validation of a questionnaire for the diagnosis of REM sleep behavior disorder. *Neurology* **58**, A509.

Bracha, H. S., Wolkowitz, O. M., Lohr, J. B., Karson, C. N. & Bigelow, L. B. (1989). High prevalence of visual hallucinations in research subjects with chronic schizophrenia. *Am J Psychiatry* **146**, 526-8.

Bristow, E., Tabraham, P., Smedley, N., Ward, T. & Peters, E. (2014). Jumping to perceptions and to conclusions: specificity to hallucinations and delusions. *Schizophr Res* **154**, 68-72.

Collerton, D. & Dudley, R. (2004). A cognitive Behavioural Framework for the Treatment of Distressing Visual Hallucinations in Older People. *Behav Cogn Psychother* **32**, 443-455.

Collerton, D., Perry, E. & McKeith, I. (2005). Why people see things that are not there: a novel Perception and Attention Deficit model for recurrent complex visual hallucinations. *Behav Brain Sci* **28**, 737-57; discussion 757-94.

Cuthbert, B. N. & Insel, T. R. (2013). Toward the future of psychiatric diagnosis: the seven pillars of RDoC. *BMC Med* **11**, 126.

Dudley, R., Aynsworth, C., Cheetham, R., McCarthy-Jones, S., & Collerton, D. (2018). Prevalence and characteristics of multi-modal hallucinations in people with psychosis who experience visual hallucinations. *Psychiatry Res.* **269** 25–30.

Dudley, R., Wood, M., Spencer, H., Brabban, A., Mosimann, U. P. & Collerton, D. (2012). Identifying specific interpretations and use of safety behaviours in people with distressing visual hallucinations: an exploratory study. *Behav Cogn Psychother* **40**, 367-75.

Fenelon, G., Mahieux, F., Huon, R. & Ziegler, M. (2000). Hallucinations in Parkinson's disease: prevalence, phenomenology and risk factors. *Brain* **123 (Pt 4)**, 733-45.

Folstein, M. F., Folstein, S. E. & McHugh, P. R. (1975). Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* **12**, 189-198.

Ford, J. M., Morris, S. E., Hoffman, R. E., Sommer, I., Waters, F., McCarthy-Jones, S., Thoma, R. J., Turner, J. A., Keedy, S. K., Badcock, J. C. & Cuthbert, B. N. (2014). Studying hallucinations within the NIMH RDoC framework. *Schizophr Bull* **40**, SS295-304.

Friston, K. (2010). The free-energy principle: a unified brain theory? *Nat Rev Neurosci* **11**, 127-38.

Graham, G., Dean, J., Mosimann, U. P., Colbourn, C., Dudley, R., Clarke, M. & Collerton, D. (2011). Specific attentional impairments and complex visual hallucinations in eye disease. *Int J Geriatr Psychiatry* **26**, 263-7.

Hohmann, A. & Haase, W. (1982). Development of visual line acuity in humans. *Ophthalmic Res* **14**, 107-12.

Inzelberg, R., Kipervasser, S. & Korczyn, A. D. (1998). Auditory hallucinations in Parkinson's disease. *J Neurol Neurosurg Psychiatry* **64**, 533-5.

Jenkinson, C., Fitzpatrick, R., Peto, V., Greenhall, R. & Hyman, N. (1997). The Parkinson's Disease Questionnaire (PDQ-39): development and validation of a Parkinson's disease summary index score. *Age Ageing* **26**, 353-7.

Johns, M. W. (1991). A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep* **14**, 540-545.

Lezak, M. D., Howieson, D. B. & Loring, D. W. (2004). *Neuropsychological assessment*. Oxford University Press: Oxford.

Lim, A., Hoek, H. W., Deen, M. L., Blom, J. D. & Investigators, G. (2016). Prevalence and classification of hallucinations in multiple sensory modalities in schizophrenia spectrum disorders. *Schizophr Res* **176**, 493-499.

Llorca, P. M., Pereira, B., Jardri, R., Chereau-Boudet, I., Brousse, G., Misdrahi, D., Fenelon, G., Tronche, A. M., Schwan, R., Lancon, C., Marques, A., Ulla, M., Derost, P., Debilly, B., Durif, F. & de Chazeron, I. (2016). Hallucinations in schizophrenia and Parkinson's disease: an analysis of sensory modalities involved and the repercussion on patients. *Sci Rep* **6**, 38152.

Makin, S. M., Redman, J., Mosimann, U. P., Dudley, R., Clarke, M. P., Colbourn, C. & Collerton, D. (2013). Complex visual hallucinations and attentional performance in eye disease and dementia: a test of the Perception and Attention Deficit model. *Int J Geriatr Psychiatry* **28**, 1232-8.

Mamiya, Y., Nishio, Y., Watanabe, H., Yokoi, K., Uchiyama, M., Baba, T. & Hashimoto, M. (2016). The pareidolia test: A simple neuropsychological test measuring visual hallucination-like illusions. *PloS One* **11**, e0154713.

McCarthy-Jones, S., Smailes, D., Corvin, A., Gill, M., Morris, D. W., Dinan, T. G., Murphy, K. C., Anthony, O. N. F., Waddington, J. L., Australian Schizophrenia Research, B., Donohoe, G. & Dudley, R. (2017). Occurrence and co-occurrence of hallucinations by modality in schizophrenia-spectrum disorders. *Psychiatry Res* **252**, 154-160.

Morrison, A. P. & Renton, J. C. (2001). Cognitive therapy for auditory hallucinations: A theory-based approach. *Cognitive and Behavioral Practice* **8**, 147-160.

Mosimann, U. P., Collerton, D., Dudley, R., Meyer, T. D., Graham, G., Dean, J. L., Bearn, D., Killen, A., Dickinson, L., Clarke, M. P. & McKeith, I. G. (2008). A semi-structured interview to assess visual hallucinations in older people. *Int J Geriatr Psychiatry* **23**, 712-8.

Mueser, K. T., Bellack, A. S. & Brady, E. U. (1990). Hallucinations in schizophrenia. *Acta Psychiatr Scand* **82**, 26-9.

Solesvik, M., Joa, I., Larsen, T. K., Langeveld, J., Johannessen, J. O., Bjornestad, J., Anda, L. G., Gisselgard, J., Hegelstad, W. T. & Bronnick, K. (2016). Visual Hallucinations in First-Episode Psychosis: Association with Childhood Trauma. *PLoS One* **11**, e0153458.

Sterzer, P., Adams, R.A., Fletcher, P., Frith, C., Lawrie, S.M., Muckli, L., Petrovic, P., Uhlhaas, P., Voss, M. & Corlett, P.R. (in press)**.** The Predictive Coding Account of Psychosis. *Biol Psychiatry.*

Taylor, J. P., Firbank, M., Barnett, N., Pearce, S., Livingstone, A., Mosimann, U., Eyre, J., McKeith, I. G. & O'Brien, J. T. (2011). Visual hallucinations in dementia with Lewy bodies: transcranial magnetic stimulation study. *Br J Psychiatry* **199**, 492-500.

Thomson, C., Wilson, R., Collerton, D., Freeston, M. & Dudley, R. (2017). Cognitive behavioural therapy for visual hallucinations: An investigation using a single-case experimental design. *The Cognitive Behaviour Therapist* **10**, E10.

Uchiyama, M., Nishio, Y., Yokoi, K., Hirayama, K., Imamura, T., Shimomura, T. & Mori, E. (2012). Pareidolias: Complex visual illusions in dementia with Lewy bodies. *Brain* **135**, 2458-2469.

Uchiyama, M., Nishio, Y., Yokoi, K., Hosokai, Y., Takeda, A. & Mori, E. (2015). Pareidolia in Parkinson's disease without dementia: A positron emission tomography study. *Parkinsonism & Related Disorders* **21**, 603-609.

Urwyler, P., Nef, T., Killen, A., Collerton, D., Thomas, A., Burn, D., McKeith, I. & Mosimann, U. P. (2014). Visual complaints and visual hallucinations in Parkinson's disease. *Parkinsonism Relat Disord* **20**, 318-22.

van der Gaag, M. (2006). A neuropsychiatric model of biological and psychological processes in the remission of delusions and auditory hallucinations. *Schizophr Bull* **32 Suppl 1**, S113-22.

Waters, F., Woods, A. & Fernyhough, C. (2014). Report on the 2nd International Consortium on Hallucination Research: evolving directions and top-10 "hot spots" in hallucination research. *Schizophr Bull* **40**, 24-7.

Wilson, R., Collerton, D., Freeston, M., Christodoulides, T. & Dudley, R. (2016). Is Seeing Believing? The Process of Change During Cognitive-behavioural Therapy for Distressing Visual Hallucinations. *Clin Psychol Psychother* **23**, 285-97.

Yokoi, K., Nishio, Y., Uchiyama, M., Shimomura, T., Iizuka, O. & Mori, E. (2014). Hallucinators find meaning in noises: Pareidolic illusions in dementia with Lewy bodies. *Neuropsychologia* **56**, 245-254.

TABLE 1. Clinical and demographic characteristics (*n* = 176)

	ED *n* = 82	**PD *n* = 41**	**LBD *n* = 31**	**Psychosis *n* = 22**	**Statistics**	***P***
Age (years)	80.07 (8.13)	72.63 (9.48)	77.65(7.58)	24.41 (4.58)	F=288.713[Z], 20.447[A], 2.079[B], 5.832[C] , 945.713[D], 503.154[E], 858.517[F]	<0.001[Z,A,D,E,F], 0.152[B], 0.018[C]
Female (%)	55 (67.1)	20 (48.8)	11 (35.5)	12 (54.5)	χ^2=10.240[Z], 3.84[A], 9.24[B], 1.27[C], 1.19[D], 0.19[E], 1.90[F]	0.017[Z], 0.05[A], 0.002[B], 0.259[C], 0.276[D], 0.663[E], 0.168[F]
Education (years)	10.66 (2.25)	10.24 (3.18)	10.08 (1.32)	n.a	F =0.557[Z], 0.697[A], 0.818[B], 0.034[C]	0.574[Z], 0.406[A], 0.368[B], 0.855[C]
Visual acuity (decimals)	0.152 (0.169)	0.370 (0.131)	0.318 (0.144)	n.a	F =28.246[Z], 52.276[A], 9.686[B], 1.292[C]	<0.001[Z,A], 0.002[B] , 0.261[C]
MMSE [max = 30]	27.33 (1.71))	26.95 (3.14)	20.52 (4.12)	n.a	F =73.171[Z], 0.760[A], 154.103[B], 56.627[C]	<0.001[Z,B,C], 0.385[A]
Verbal fluency (words per minute)	12.57 (5.58)	12.26 (5.89)	6.11 (4.56)	n.a	F =3.568[Z], 0.069[A], 7.47[B], 5.97[C]	0.032[Z], 0.793[A], 0·008[B] ,0.019[C]
Categorical fluency (animals per minute)	14.92 (4.04)	15.88 (5.91)	9.20 (3.45)	n.a	F =12.826[Z], 0.497[A], 24.830[B], 21.785[C]	<0.001[Z,B,C], 0.483[A]
Parkinsonism duration (years)	n.a	8.32 (4.27)	3.75 (3.28)	n.a.	F =11.657[C]	0.001[C]
UPDRS Motor [max = 67]	n.a	24.39 (11.62)	27.88 (15.67)	n.a	F =1.831[Z], 0.877[C]	0.170[Z], 0.353[C]
ESS [max = 24]	5.5 (0.71)	8.71 (5.62)	12.50 (0.71)	n.a	F =0.818[Z], 0.636[A], 98.0[B], 0.889[C]	0.448[Z], 0.430[A], 0.010[B], 0.351[C]
RBD likely (%)	1 (1)	13 (31.7)	9 (45)	n.a	χ^2=1.19[Z], 0.291[A], 0.018[B], 1.03[C]	<0.001[Z], 0.550[A] 0.714[B], 0.310[C]

Data are mean and (SD) unless specified otherwise; Statistics are one-way ANOVA (F) or chi-square (χ2) tests or °Fisher's Exact; MMSE = Mini-Mental State Examination, UPDRS = Unified Parkinson's Disease Rating Scale, ESS = Epworth Sleeping Scale; RBD = Rapid eye movement sleep behaviour disorder; ED = Eye disease; PD = Parkinson's disease; LBD = Lewy body dementia; n.a = not available; Z comparison across all groups, df =3; [A] ED vs. PD, df =1; [B] ED vs. LBD, df =1; [C] PD vs. LBD, df =1; [D] ED vs. Psychosis, df =1; [E] PD vs. Psychosis, df =1; [F] LBD vs. Psychosis, df =1;

TABLE 2. The prevalence of other hallucination modalities in combination with visual hallucination across disorders

	ED *n* = 81	**PD *n* = 39**	**LBD *n* = 28**	**Psychosis *n* = 22**	**Statistics**	***p***
Unimodal (%)	78 (96.3)	35 (89.7)	19 (67.9)	3 (13.6)	χ^2=92.526^{Z}, 113.00^{A}, 97.00^{B}, 54.00^{C}, 81.00^{D}, 38.00^{E}, 22.00^{F}	<0.001^{Z,A,B,C,D,E}, 0.001^{F}
MMH (%)	3 (3.7)	4 (10.3)	9 (32.1)	19 (86.4)	χ^2=18.731^{Z}, 7.00^{A}, 12.00^{B}, 13.00^{C}, 22.00^{D}, 23.00^{E}, 28.00^{F}	<0.001^{Z,E,F}, 0.029^{A}, 0.005^{B}, 0.001^{C}, 0.001^{D}
	n = 27$^{\#}$	**n = 39$^{\#}$**	**n=18$^{\#}$**	**n=22$^{\#}$**		
Tactile (%)	3 (11.1)	3 (7.7)	5 (27.8)	18 (81.8)	χ^2=44.01^{Z}, 0.226^{A}, 2.05^{B}, 4.12^{C}, 24.747^{D}, 34.236^{E}, 11.831^{F}	<0.001^{Z,D,E}, 0.635^{A} , 0.152^{B}, 0.042^{C}, 0.001^{F}
	n = 80§	**n=39§**	**n=28§**	**n=22§**		
Auditory	1 (1.3)	1 (2.6)	6 (21.4)	16 (72.7)	χ^2=78.39^{Z}, 0.274^{A}, 13.93^{B}, 6.19^{C}, 63.472^{D}, 34.446^{E}, 13.158^{F}	<0.001^{Z,B,C,D,E,F}, 0.601^{A}, 0.013^{C}
	n = 2$^{¥}$	**n = 39$^{¥}$**	**n = 18$^{¥}$**	**n = 22$^{¥}$**		
Olfactory (%)	0 (0)	1 (2.6)	1 (5.6)	6 (27.3)	χ^2=10.42^{Z}, 0.053^{A}, 0.117^{B}, 0.326^{C}, 0.727^{D}, 8.453^{E}, 3.234^{F}	0.015^{Z}, 0.819^{A} 0.732^{B}, 0.568^{C}, 0.394^{D}, 0.004^{E}, 0.072^{F}

Data are n (%); Statistics are chi-square (χ^2) or Fisher's exact tests; ED = Eye disease; PD = Parkinson's disease; LBD = Lewy body dementia; MMH = multimodal hallucinations

^{Z} comparison across all groups: df = 3; ^{A} ED vs. PD: df = 1; ^{B} ED vs. LBD: df = 1; ^{C} PD vs. LBD: df = 1; ^{D} ED vs. Psychosis, df =1; ^{E} PD vs. Psychosis, df =1;

^{F} LBD vs. Psychosis, df =1; # = number of answers to sections corresponding to tactile hallucination; § = number of answers to sections corresponding to auditory hallucination; ¥ = number of answers to sections corresponding to olfactory hallucination;

TABLE 3. Emotional response and Conviction towards VH in MMH

	Unimodal *n* = 135	**MMH *n* = 35**	**Statistics**	***p***
Type of emotional response				
Irritating/frustrating (%)	47 (33.3)	30 (78.9)	χ^2=25.407; df=179	<0.001
Distressing/frightening (%)	46 (32.6)	30 (78.9)	χ^2=26.291; df=179	<0.001
Conviction				
Belief VH is real (%)	31 (60.8)	26 (86.7)	χ^2=6.069; df=81	0.014

Data are n (%); Statistics are chi-square (χ^2) tests